

**THEORIES REGARDING THE AETHER, by Professor A. D. Ross, M.A., D.Sc., F.R.S.E.**

(Presidential Address—*Read* July 8, 1924; *issued* September 15, 1924.

Despite the importance of electricity from the practical standpoint, it is doubtful whether any other branch of physical science has aroused so much interest as the study of Light. The beauty and variety of optical phenomena, the relative importance of our sense of sight, the fact that light is the main vehicle of interplanetary and interstellar communication—all these make Optics fascinating to the general student as well as to the scientist.

In early times man speculated regarding the nature of light. In the sixth century B.C. Pythagoras suggested an emission theory, but about 350 B.C. Aristotle opposed the idea that light was material, considering it to be a quality or action (Greek, *energeia*) of a medium which he called the pellucid (Greek, *diaphanes*). In his writings we find the suggestion of the theory of an aether, a theory afterwards developed by Grimaldi (1618-1663), Huygens (1629-1695), Thomas Young (1773-1829), and Fresnel (1788-1827). Since the seventeenth century the celestial bodies have no longer been regarded as isolated in space, but as immersed in an aethereal ocean which permitted an incessant conveyance and transmutation of energy. Thus arose the problem, not yet completely solved, as to the relationship which subsists between this luminiferous medium which fills the known universe and the aggregations of matter which occur here and there throughout it.

The problem may be said to have originated in the speculations of René Descartes (1596-1650) in his endeavours to create from the beginning a complete system of human knowledge. While his work was necessarily metaphysical, he also aimed at a mechanical explanation of nature.\* He regarded the universe as an immense machine operated by the motion and pressure of matter. "Give me matter and motion and I will construct the universe." He repudiated all idea of action at a distance. Force could not be communicated save by actual pressure or impact, and hence it became necessary to provide explicit mechanism for each known force in nature. He considered that the sun and stars consist of a subtle form of luminous matter and form the centres of immense vortices. They are surrounded by a transparent plenum consisting of an

\* See his *Dioptrique* (1638), *Météores* (1638), and *Principia Philosophiæ* (1644).



assemblage of minute spherical particles or globules. The luminous matter and the transparent matter, owing to the centrifugal force of the vortices, are straining away from the rotation centres. The particles press outwards, but, owing to their contact one with another, they cannot so move, and it is this pressure which constitutes light. The transmission of light from luminous matter (say the sun) to opaque matter (say the earth) through the medium of the transparent matter plenum was thus compared to a blind man's perception of the presence of objects by the transmission of pressure from particle to particle along a stick. The diversities of colour and light were ascribed to the different ways in which matter moves and the various colours were connected with different rotatory velocities of the globules.\* This association of colour with periodic time was a strange foreshadowing of one of Newton's great discoveries. The law of refraction of light† was established by aid of analogy with the motion of ponderable matter, but the proof required light to move more rapidly in dense than in rare media. Descartes, probably interested by the celebrated treatise "*De Magnete*" published by William Gilbert in 1600, attempted to account for magnetic phenomena by his theory of vortices. A vortex of fluid matter was imagined for each magnet, the vortex matter entering by one pole and leaving by the other. This matter was supposed to act upon iron and steel by a special resistance offered to its motion by the molecules of such metals. The Cartesian system of the universe was doubtless crude in many of its features, but it emphasised the importance of a broad generalisation of knowledge and unification of ideas (such as we now have in the electromagnetic theory of light), and the necessity of considering the relationship between ordinary ponderable matter and the plenum of space.

Robert Hooke (1635-1703), one of the founders of the Royal Society of London, was both an observer and a theorist. He experimented on the colours of thin plates,‡ and the illumination in the geometrical shadow of opaque bodies due to diffraction,§ in both of which matters he had however been anticipated.¶ He was led to theoretical investigations representing a transition from the Cartesian to the fully developed theory of undulations. He took exception to Descartes' view that light is a tendency to motion rather than an "exceedingly quick motion," and from various observations deduced that the motion was of a to-and-fro or vibratory character and of excessively small amplitude. He then stated the necessary properties of the pellucid or transparent medium. It must be homogeneous, susceptible to the vibrations of luminous

\* *Principia*, Part iv., par. 195, and *Discours Huitieme*.

† *Dioptrique*, *Discours second*.

‡ *Micrographia*, p. 47.

§ *Posthumous Works*, p. 186.

¶ Boyle's *Works* (ed. 1772), Vol. i., p. 742; Grimaldi *Physico-Mathesis de lumine, caloribus, et iride* (1665), book i, prop. 1.



bodies, and capable of transmitting this appulse to the maximum distance in the minimum time. Further this propagation must be in straight lines in homogeneous media, the wave-front extending out as an expanding sphere. Hooke was also able to give a mechanical theory of refraction, and his was an advance on Descartes' theory in that the velocity of propagation was less in dense than in rare media. He regarded white light as the simplest type of disturbance, consisting of a pulse at right angles to the direction of propagation, while the prismatic colours arose from the deflection of the wave-front. "The ray is dispersed, split, and opened by its refraction at the superficies of a second medium, and from a line is opened into a diverging Superficies, and so obliquated, whereby the appearance of Colours are produced."\*

This theory of colour was however completely overthrown by Sir Isaac Newton (1642-1727), who, by his historic experiment in 1666 on the formation of a prismatic spectrum, discovered that ordinary white light is really a mixture of rays of every variety of colour. At first Newton strove merely to arrive at the general laws of optical phenomena without attempting to formulate hypotheses as to the ultimate nature of the optical processes. He found however that it was impossible to go far without having recourse to hypotheses. He then rejected Hooke's idea that light consists in vibrations of an aether, owing to the apparent incompetence of the wave-theory to account for the rectilinear propagation of light and to explain the phenomena of polarisation. He considered the universe to be filled with an elastic medium or aether which is capable of propagating vibrations in the same way as air propagates sound. The aether penetrates all material bodies and is the cause of their cohesion, while its density varies from one body to another but is greatest in free interplanetary space. It is not necessarily a single uniform substance but may contain various aethereal "spirits" which are respectively adapted to give rise to the phenomena of electricity, magnetism, and gravitation. He suggested† that light might consist of multitudes of unimaginable small and swift corpuseles of various sizes emitted by luminous bodies. Or it might consist in some "corporeal emanation, or any impulse or motion of any other medium or aethereal spirit diffused through the main body of aether." He let everyone form his own ideas, only reserving the supposition that light at least "consists of rays differing from one another in contingent circumstances, as bigness, form, or vigour." Aether was then the intermediary between light and ponderable matter. When a ray of light met an aether stratum of density different from that of the stratum in which it had been travelling, it was, in general, deflected from its previous course. Moreover the condensation

\* Hooke, *Posthumous Works*, p. 82.

† Roy. Soc., 9th Dec., 1675.



or rarefaction of the aether due to a material body extended to some little distance from the surface of the body, and so diffraction was "only a new kind of refraction." To those who assumed with Newton that light is not actually constituted by vibrations of an aether—even though such vibrations may exist in close connection with it—the most natural supposition to make was that rays of light are streams of corpuscles emitted by luminous bodies. So, while Newton left a wide choice of hypotheses open, one was invariably selected by the scientific men of the age, and by later writers it has generally been associated with Newton's name. And there is little doubt that this hypothesis was the one which Newton found most convenient in picturing the mechanism in optical phenomena. We find then that Newton supported an emission theory of light, but postulated an all-pervading aether which was modified at least in respect to density by ponderable matter, not only within the material bodies but also in their immediate vicinity. An aether was necessary, as it was differences in density of aether between one material medium and another which accounted for the reflection and refraction of light.

Christiaan Huygens (1629-1695) greatly improved and extended the wave-theory shortly after Roemer's discovery in 1675 of the finite velocity of propagation of light. In his *Traité de la lumière* published in 1690 he improved on Hooke's conception of an outward moving spherical pulse or wave by considering that each surface-element of the wave-front may be regarded as becoming the source of a secondary wavelet, and that the advancing wave-front is the envelope of all such secondary wavelets. He was able to apply this successfully to the explanation of reflection, refraction, and of double refraction in Iceland spar. It was this last mentioned phenomenon which had compelled Newton to abandon the hypothesis that light consisted of waves analogous to waves of sound. On this point Newton was perfectly correct, but while his objection was valid against the wave-theory held by his contemporaries, it was not valid against the theory in the form in which it was stated in the eighteenth century by Young and Fresnel. As Newton said,\* "A ray of light obtained by double refraction differs from a ray of ordinary light in the way that a rod of rectangular cross-section differs from a rod of circular cross-section, and it was impossible for a ray to exhibit sides" if it consisted of longitudinal vibrations as in sound propagation.

With the exception of the announcement in 1728 of the discovery of the aberration of light from observations made in 1725-6 of the star *Gamma Draconis* by James Bradley (1692-1762), there was little advance in optical science until the nineteenth century. The aberration of light too was more easily explained on the corpus-

\* Newton, *Opticks* (2nd ed.), queries 26 and 28.



cular than on the wave-theory, and it certainly strengthened the supporters of the former hypothesis.

Thomas Young (1773-1829) began to write on optics in 1799. In his first paper\* he draws attention to the difficulty in explaining on the corpuscular theory of light why the velocity of emission of a corpuscle should be the same whether the projecting force was that of a feeble spark or the intense heat of the sun itself. A further passage contains a marvellous prophecy of an electric theory of light: "That a medium resembling in many properties that which has been denominated ether does really exist, is undeniably proved by the phenomena of electricity. The rapid transmission of the electric shock shows that the electric medium is possessed of an elasticity as great as is necessary to be supposed for the propagation of light. Whether the electric ether is to be considered the same with the luminous ether, if such a fluid exists, may perhaps at some future time be discovered by experiment." In 1801 he made a great advance in optics in explaining on the wave-theory the phenomenon of Newton's rings by accepting the composite nature of white light and considering the mutual reënfacement and interference of two beams.† In 1803 he applied the theory of interference to the explanation of diffraction phenomena.‡ The year 1817 witnessed a still greater triumph on his part. A consideration of the results of experiments on the interference of polarised light convinced him that the vibrations in light rays were transverse and not longitudinal.§ This showed very considerable insight, for it is to be remembered that the theory of propagation of waves in an elastic solid was yet unknown, and light was always considered by analogy with the vibrations in sound waves.

Augustin Fresnel (1788-1827) had been working for some years on the subject of optics when Young's announcement of the transverse vibrations in light rays was made. He at once realised that this hypothesis fitted in marvellously with the phenomena of crystal optics, and the remainder of his life was devoted to the elucidation of polarisation effects in crystals. In an important memoir|| he states "The theory which I have adopted, and the simple constructions which I have deduced from it, have this remarkable character, that all the unknown quantities are determined together by the solution of the problem. We find at the same time the velocities of the ordinary ray and of the extraordinary ray, and their planes of polarisation. Physicists who have studied attentively the laws of nature will feel that such simplicity and such close relations between the different elements of the phenomenon are conclusively in favour of the hypothesis on which they are based."

\* *Phil. Trans., Roy. Soc.*, 1800, p. 106.

† *Phil. Trans., Roy. Soc.* (1802), pp. 12, 387.

‡ *Phil. Trans., Roy. Soc.* (1804): *Young's Works*, i., p. 179.

§ *Young's Works*, i., p. 380.

|| *Mem. de l'Acad.*, vii., p. 45 (1827); *Fresnel, Oeuvres*, ii., p. 479.



By the genius of Young and Fresnel the wave-theory of light was firmly established a century ago, but so far the theory was not strictly a dynamical theory, as the qualities of the aethereal medium had not been defined. They had pointed out that the existence of transverse vibrations might be explained by conferring a new property on the luminiferous aether, viz., giving it power to resist attempts to distort its shape. Clearly there were difficulties in the way. This power to resist change of shape is the property which distinguishes solids from fluids. Could the aether be an elastic solid while the planets and comets moved through it? Sir George Gabriel Stokes (1819-1903) in 1845 drew attention to the fact that such substances as pitch and shoemakers' wax, though so rigid as to be capable of elastic vibration, are yet sufficiently plastic to permit other bodies to pass slowly through them.\* The aether might then have this combination of qualities in an extreme degree, behaving as an elastic solid for vibrations so rapid as those constituting light, but yielding like a fluid to the much slower progressive motions of the planets.

This suggestion by Stokes gave an impetus to the development of the theory of elasticity, and we have the important researches of Cauchy, MacCullagh, Neumann, Green, and Boussinesq, some of whom paid considerable attention to the application of their general theory to optical phenomena. In this connection it is noteworthy that Boussinesq clearly indicated† that all space, both within and without ponderable bodies, is occupied by one identical aether, the same everywhere both in inertia and in elasticity, and further that all aethereal processes are to be represented by two kinds of equations, of which one kind expresses the invariable equations of motion of the aether, while the other kind expresses the interaction between aether and matter. Many years afterwards these ideas were revived in connection with the electromagnetic theory, in the modern forms of which they are indeed of fundamental importance. William Thomson, Lord Kelvin (1824-1907) and James Clerk-Maxwell (1831-1879) were also pioneers in this elastic solid theory of the aether, and a noteworthy feature of their work was their mechanical models of the aethereal medium. However, these physicists were led into this field through electrical rather than optical investigations, and we must here glance back at the development of electrical theory.

The experiments of Petrus Peregrinus in the thirteenth century in locating the magnetic poles of a piece of lodestone were instrumental in calling the attention of William Gilbert (1540-1603) to the necessity for detailed study of both magnetic and electric

\* *Trans. Camb. Phil. Soc.*, viii., p. 287.

† *Journ. de Math.* (2) xiii., pp. 313, 425 (1868); *Comptes Rendus*, cxvii., pp. 80 139, 193 (1893).



phenomena. He imagined that electric phenomena were due to something of a material nature, which, under the friction used in the process of electrification, is liberated from the glass, amber, sulphur, or sealing-wax, in which under ordinary circumstances it is imprisoned. The friction might conceivably warm or otherwise excite and liberate this humour or effluvium so that it emerged as an atmosphere surrounding the electrified body. Gilbert's theory of electric emanations naturally commended itself to the physicists of the seventeenth century, as it obviated all assumption of action at a distance. The mutual attraction of the electrified body and a light object in its neighbourhood could be explained by imagining the effluvia to have a tendency to condense in other bodies and to have an inherent contractile tendency, or, if preferred, a vortex theory of effluvia might be adopted. The announcement in 1729 by Stephen Gray of his discovery of electric conduction made it impossible to consider that electric effluvia were inseparably connected with the bodies from which they were evoked by friction, and it became necessary to postulate for them an independent existence. Their apparent imponderability was no difficulty to the scientists of the period who were accustomed to include caloric and light in the list of chemical elements.

Soon after this rival theories of electricity developed. Du Fay (1698-1739) showed by a series of experiments that there were apparently two kinds of electricity,\* vitreous and resinous, while in 1747 Benjamin Franklin (1706-1790) suggested a one-fluid theory.† The important point, however, was that both theories agreed with the suggestion put forward in 1746‡ by William Watson (1715-1787), that electricity is neither created nor destroyed in the charge or discharge of a Leyden jar but is something which is transferred. These advances rendered adherence to the electric effluvia theory increasingly difficult. Originally it had been supposed that this material was normally present in glass, but could be brought out by frictional electrification, but Franklin's theory of the Leyden jar required glass to be impermeable to electricity. The theory of effluvia was finally overthrown by Aepinus (1724-1802), who found that a condenser could be made with air as the medium separating the two plates. The electric fluid did not then extend beyond the surface of the charged body, and this result, combined with Stephen Gray's observation in 1729 of the similar effects produced by electrified solid and hollow cubes, indicated that the fluid when at rest was confined to the surface of the charged bodies. This established, it appeared that electricity can act at a distance across intervening space.

\* *Mem. de l'Acad.*, 1733, p. 464.

† Franklin, *New Experiments and Observations on Electricity*, letter ii.

‡ *Phil. Trans. Roy. Soc.*, xliv., p. 718.



The discovery of galvanic or voltaic electricity in the closing years of the eighteenth century opened another method of approaching the subject. For the researches of Oersted (1777-1851), Ampère (1775-1836), Gauss (1777-1855), and Weber (1804-1890) in electrodynamics demanded the existence of an electric medium—not a medium which constituted the electricity itself, but a medium through which the electric and magnetic actions could be exerted. In the hands of Faraday (1791-1867) it was shown\* that all the effects of electricity (magnetic, thermal, luminous, chemical, mechanical, and physiological) are obtained equally well whether the electricity has a frictional or voltaic source. In 1838 he advanced a theory of electrostatic induction† in which he compared the particles of the insulating dielectric to a series of small magnetic needles, or a series of small insulated conductors. This conception of action, propagated step by step through a medium by the influence of contiguous particles, was fundamental in Faraday's work. It was carried by him into almost all branches of science, and sufficed to explain electric currents. In 1845 he was successful in finding experimentally a connection between magnetism and light, the powerful field of an electromagnet rotating the plane of polarisation of a beam of light travelling along the lines of magnetic force in a piece of heavy glass.‡ This led him in the following year to publish a short paper on "*Thoughts on Ray Vibrations*"§ which contains the germ of an electromagnetic theory of light. In this paper he suggests that atoms of ponderable matter may be merely fields of force of electric, magnetic or gravitational character surrounding a point-centre, and, as lines of force radiate out through space, light and radiant heat might be transverse vibrations propagated along these lines of force. Hence Faraday suggested the dismissal of the aether, or rather its replacement by lines of force between centres. If the postulation of a luminiferous aether was desirable, Faraday considered that it might also be the vehicle of magnetic force, for it seemed to him not at all unlikely that it should have other uses than merely the conveyance of radiations.

These ideas of Faraday were wonderfully developed by James Clerk-Maxwell (1831-1879) in his electromagnetic theory of light. Thomson|| had compared electric force to displacement in an elastic solid. Faraday had supposed¶ that when the dielectric is subjected to an electrostatic field, there is a displacement of electric charge on each of the small conductors to which he had likened the particles of a ponderable dielectric; and the motion of these charges

\* Faraday, *Experimental Researches*, series iii.

† Faraday, *Experimental Researches*, par. 1679.

‡ Faraday, *Experimental Researches*, par. 152.

§ *Phil. Mag.* (3), xxviii (1846); *Experimental Researches*, iii., p. 447.

|| *Camb. & Dublin Math. Journ.*, ii. (1847), p. 61; Thomson, *Math. & Phys. Papers*, i., p. 76.

¶ Faraday, *Experimental Researches*, par. 1679.



when the field was varied, was equivalent to an electric current. Maxwell, in adopting Faraday's idea, transformed it; for, whereas the conception of displacement had been applicable only to ponderable dielectrics, with Maxwell\* there is displacement wherever there is electric force whether material bodies are present or not. The so-called displacement is, however, in these latter theories a change of structure rather than a change of position in the elements of the aether.

Through various vicissitudes, the idea of an aether has come down to us through the centuries. Even when it was most in disfavour we can see that the replacing hypotheses were suggested by some phase of its supposed action. And the idea has been pregnant with scientific advances. Thus in 1853 Thomson investigated the mathematical theory of the discharge of a condenser showing† the conditions under which the discharge was oscillatory and how to determine the frequency. Maxwell's discussion of the dynamics of the electromagnetic field showed that there was another phase of the problem to be considered, namely, the radiation of electromagnetic energy. In this way he was led to the idea of waves of widely varying frequencies emitted from oscillating systems. In 1888 Heinrich Hertz (1857-1894) was successful in obtaining such waves and in showing that their velocity of propagation was, as Maxwell's theory demanded, the same as that of light.‡ As the years have passed the gamut of electromagnetic waves from gamma rays of length 0.000,000,007 millimetres to wireless waves of lengths exceeding 50 kilometres has been fairly well explored. Between the gamma or Roentgen rays and the ultraviolet rays of the Schumann region there is still a gap of nearly five octaves (0.000,001,2 to 0.000,036 millimetres). Again between the longest radiations from the quartz mercury lamp (0.342 mm.) to the shortest electric waves known (2 mms.) there is a gap of a little over two octaves. Otherwise we have knowledge of waves extending 15 or 16 octaves below and some 26 octaves above the luminous radiations. Many of these radiations are of considerable importance, and there is a little doubt that the call of pure science and the fascination of aether theory have helped materially in their discovery and investigation. Maxwell's theory also proved§ what had been anticipated by Euler,|| that light should exert a pressure, and this result was confirmed experimentally many years later.¶

\* *Phil. Mag.*, xxi. (1861), pp. 161, 281, 338; xxiii. (1862), pp. 12, 85; Maxwell, *Scientific Papers*, i., p. 451.

† *Phil. Mag.* (4) v. (1853), p. 400; Kelvin, *Math. & Phys. Papers*, i., p. 540.

‡ *Ann. d. Phys.*, xxxiv. (1888), p. 551.

§ Maxwell, *Treatise on Electricity and Magnetism*, par. 792.

|| *Histoire de l'Acad. de Berlin*, ii. (1748), p. 117.

¶ P. Lebedew, *Ann. d. Phys.*, vi. (1901), p. 433. E. F. Nichols and G. F. Hull, *Phys. Rev.*, xiii. (1901), p. 293.



The writer has discussed elsewhere\* the results of attempts to solve the problem of the relative motion of matter and the aether. The results have been bewildering. Bradley's aberration discovery of 1728 is most easily explained on the assumption that the earth moves freely through the aether, and Young in 1804 showed that this assumption applies equally as well on a wave theory as on the corpuscular emission theory. Fresnel in 1818 derived a formula for an aether drift, indicating a drag on the aether by matter whose refractive index differed from unity. This formula was supported by experiments in 1852 by Fizeau on light travelling in moving water, and by aberration tests in 1871 by Airy with a telescope filled with water. As Maxwell in his theories treated matter merely as a modification of the aether, distinguished only by altered values of certain constants, we may say that he assumed that matter and aether move together. Michelson and Morley's experiment of 1887 appeared to show a complete drag of the aether by the earth, but Lodge in 1892 could obtain no apparent effect on the aether by the rapid rotation of a massive flywheel. Such discordant results could be reconciled only by some such revolutionary theory as that advanced by Fitzgerald in 1892† or by Einstein in 1905.‡ The difficulties which have arisen in connection with theories of the aether are therefore responsible for giving us one of the greatest contributions to physical science and to philosophy—the theory of relativity. It is therefore good to know that while Einstein set out by ignoring (without affirming or denying) the aether, he finds it useful in later papers to introduce it, though for a novel purpose. All matter is transparent to gravity, although in most cases opaque to light through absorption. Current research is occupied principally with the attempt to explain these anomalies by a scrutiny of the internal structure of the atom and a fine-grained aether possessing some of the properties of matter. The history of the aether is undoubtedly a lesson on the value of interaction between theory and experiment, and of the contribution of pure to applied science.

† *Journ. Roy. Soc. W.A.*, v., p. 89 : Ross, *Einstein's Theory of Relativity*, p. 7.

\* Lodge, *Nature*, xlv. (1892), p. 165.

‡ Einstein, *Ann. d. Phys.*, xvii. (1905), p. 891.